CHAPTER 2
DESCRIPTION OF EQUIPMENT

SECTION I. BOILERS AND HEAT EXCHANGERS

2-1. BOILER CLASSIFICATIONS.

There are a few fundamental types of boilers and many variations of each type. Boilers are generally classified according to the relative position of combustion gases and water as either fire tube or water tube. Boilers are also classified by the form of energy produced; low or high pressure steam; low, medium, or high temperature water. Other methods of classifying boilers are listed below.

— Type of Water Circulation - natural circulation, forced circulation.

— Type of Steam Produced - saturated, superheated.

— Method of Assembly - package, modular, field erected.

— Type of Use - stationary, marine, power, heating.

— Type of Fuel - coal, oil, gas.

— Method of Combustion- spreader stoker, fluidized bed, pulverized coal.

— Boiler Capacity - Up to 20,700 pounds per hour (up to 600 horsepower) for fire tube boilers; up to 10,000,000 pounds per hour for water tube boilers; up to 200 million Btu per hour for hot water boilers.

2-2. BOILER DESIGN REQUIREMENTS.

A boiler must meet the following requirements:

— Operational safety.

— Generation of clean steam or hot water at the desired rate, pressure, and temperature.

— Economy of operation and maintenance.

— Conformance to applicable codes.

A set of rules for the construction and operation of boilers, known as the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vellel Code, has been widely adopted by insurance underwriters and government agencies. Section I of the Code contailns requirements for power boilers including methods of construction and installation, materials to be used, design, accessories, and inspection. Section IV of the Code contains requirements for heating boilers. Low pressure steam boilers and low temperature water boilers are classified as heating boilers. Section VI of the Code provides "Recommennded Rules for Care and Operation of Heating Boilers" and Section VII provides "Recommended Rules for Care of Power Boilers." Other sections of the Code provide material specifications, nuclear equipment requirements, inspection requirements, and welding qualifications. To meet the above listed requirements, a boiler must have the following characteristics:

— Adequate water or steam capacity.

— Properly sized steam/water separators for steam boilers.

— Rapid, positive, and regular water circulation.

— Heating surfaces which are easy to clen on both water and gas sides.

— Parts which are accessible for inspection and repair.

— Corret amount land proper arrangement of heating surface.

— A furnace of proper size and shape for efficient combustion and for directing the flow of gases for efficient heat transfer.

2-3. FABRICATION.

All boilers, superheaters, economizers, and other pressure parts must be built using materials and construction methods specified by the applicable Code sections. Repairs to boilers must also be made in accordance with Code requirements. Equipment built and inspected in accordance with the Code must have an ASME stamp. An "H" in a cloverleaf is stamped on heating boilers. An "S" in a cloverleaf is stamped on power boilers.

a. Drums, Shells, Headers. Boiler drums, shells, or headers are used to collect steam or hot water generated in the boiler and distribute it as necessary within the boiler tubes. These components must be strong enough to contain the steam or hot water that is generated and to lmechanically hold the boiler tubes as they expand and contract with changes in temperature. The shells of fire tube boilers may be reilnforced by the use of stays to hold the boiler heads in place. These components are generally fabricated with welded seams and connections. Riveted seams are no longer used, although many old rivered boilers are still in operation.

b. Boiler Tubes. Boiler tubes carry water, steam, or flue gases through the boiler. Boiler tubes are installed by expanding or welding them into seats in the drums or headerss. The expander tool consists of a tapered pin which fits into a cage containing several small rollers. A ldifferent size expander is required for ech size tube. Durilng installation, the expander is slipped into the end of the tube and the tapered pin is pushed into the cage until the rollers are against the tube walls. Then the pin is turned with a wrench or motor, forcing the rollers out against the tube, and simultaneously moving the cage into the tube. This action distorts and stretches the tube, forcing it to make a tight seal against the tube sheet. The expander often has a stop which helps prevent overexpanding, as shown in figure 2-1. Boiler tubes are installed with ends projecting slightly beyond the tube sheets. Projecting ends are flared slightly in water tube boilers and allowed to remain because they are surrounded and cooled by water or steam. Since tube ends of a fire tube boiler are surrounded by hot gases, they would soon burn off if allowed to project. They are therefore beaded and hammered until flat against the tube sheet. This process also increases the holding power of the tube. It must, however, be performed carefully to avoid injuring the tube. Figure 2-2 illustrates flared and beaded tubes.

c. **Baffles.** Baffles are thin walls or partitions installed in water tube boilers to direct the flow of gases over the heating surface in the desired manner. The numer and position of baffles have a marked effect on boiler efficiency. A leaking or missing baffle permits gases to short-circuit through the boilers. Heat which should have been absorbed by the water is then dissipated and lost. With a leaking baffle, tubes may be damaged by the "blow-torch" action of the flame or hot gas sweeping across the tube at high velocity, especially if the leak is in or near the furnace. Baffles may be made of iron castings, sheet-metal strips, brick, tile, or plastic refractory. Provision must be made to permit movement between baffle and setting walls while still maintaining a gas-tight seal. Iron castings are made in long, narrow sections to fit in the tube lanes and around the tubes. They can be installed only while the boiler is being erected or assembled, and their use is limited by the temperatures which they can withstand. Sheet-metal strips are formed to fit around the tubes and are easily installed after tubes are in the boiler. Their primary uses are to help distribute flue gas within a pass and to maintain proper tube spacing, rather than to function as baffles between adjacent passes. This type baffle cannot be used in the high-temperature areas of the boiler. Brick or tile baffles, lmade of specially shaped forms which fit between and around lthe tubes, can be installed after the boiler has been erected and ean be used in any area of the boiler. Castable plastic refractory baffles are usually installed by building a form and pouring the refractory like concrete. The forms are then removed after the refractory has set. This type of baffle can be used at any location in the boiler and, if properly designed, can remain gas-tight for long periods. It may be used to repair or replace other types of baffles.

2-4. FIRE TUBE BOILERS.

Many of the first steam boilers produced were designed with the products of lcombustion passing inside the tubes. Fire tube boiler design has developed primarily in the direction of the Scotch-type boiler shown in figure 2-3. The Scotch oboiler is shop-fabricated and is capable of supplying saturated steam at pressures below 250 psig at capacities below 20,000 lb/hr. At pressurs above 250psig, the natural circulation of water and steam in this design is not adequate for good heat transfer. At capacities above 20,000 lb/hr the shell diameter becomes too large to be economical. Scotch boilers come in two, three, and four gas pass designs, as illustrated in figure 2-4. With more gas passes and more heat transfer surface, boiler exit gas temperatures are lower and efficiencies higher. Wet-back construction in a Scotch boiler means that a water wall is provided at the outlet of the first pass or furnace. Wet-back construction reduces the high maintenance costs often associated with dry-back designs. Scotch-type fire tube boilers can effectively fire natural gas and fuel oils. Coal is a less desirable fuel because the fire tubes are not easily cleaned and ash removal is restricted. Advantages of the Scotch boiler include the ability to respond to rapid load swings due to the large volume of stored water/steam in the shell, low initial cost, low maintenance costs, and general ease of control. Disadvantages include the difficulty of producing superheated steam and pressure and apacity limitations. Scotch boilers are also used to produce low temperature water. The other common type of fire tube boiler is the horizontal return tubular (HRT) design, illustrated in figure 2-5. The firebox in this type of boiler permits the burning of coal lusing stokers or fluidized beds.

2-5. WATER TUBE BOILERS.

Water tube boilers were developed for a variety of reasons, including the need for higher pressures, higher capacities, superheated steam, faster response to load hanges, and increased safety due to the reduced water volume. Water tube boilers have water inside the tube and the flue gases on the outside. The early straight-tube design boilers were replaed with today's bent-tube designs to inrease the amount of available heat transfer surface, solve mechanical problems, and general economic reasons. Figure 2-6 illustrates a four-drum boiler with a water-cooled back wall. The bottom drum is called a mud drum beecause of the tendency of boiler sludge to collect in this low area. The upper drums are called steam drums. Water enters the top rear drum, passes through the tubes to the bottom drum, and then up through the tubes to the two front drums. A mixture of steam and water is discharged into these drums; steam returns to the top rear drum through the upper row of tubes while water travels through tubes in the lower rows. Steam is removed near the top of the rear drum by a dry pipe extending across the drum, and is discharged through the steam outlet header. The baffles are arranged to encourage flue gas flow over all the boiler

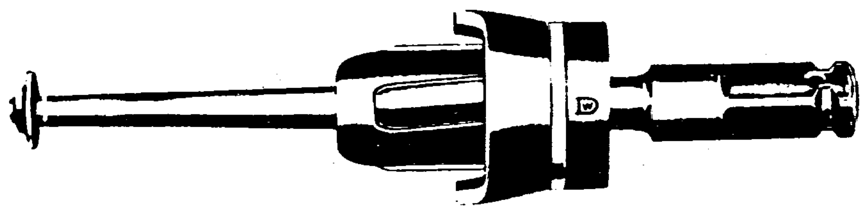
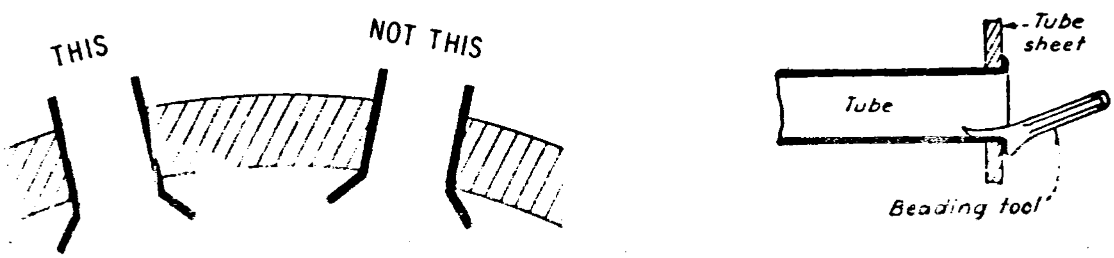


FIGURE 2-1. TUBE EXPANDER



FLARED TUBE

BEADED TUBE

FIGURE 2-2. FLARED AND BEADED TUBES

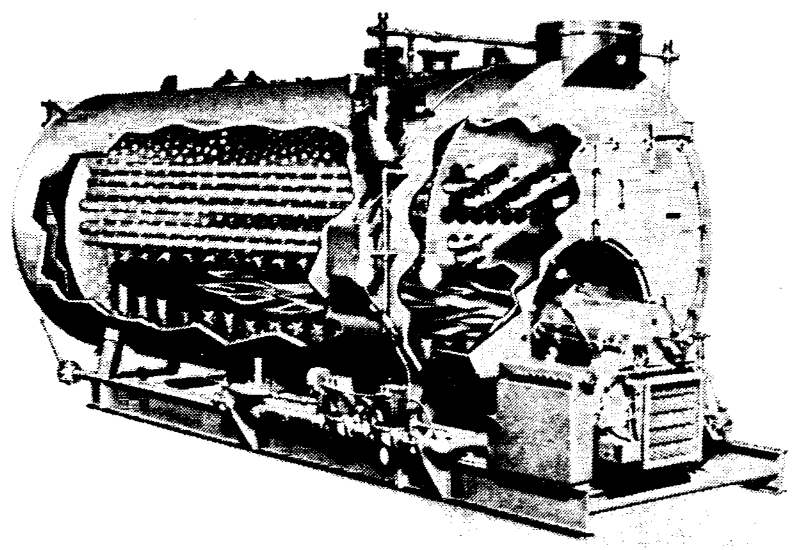
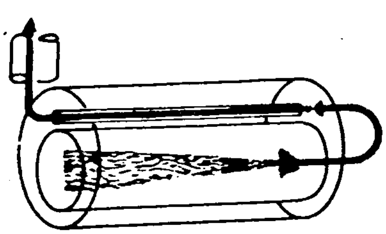
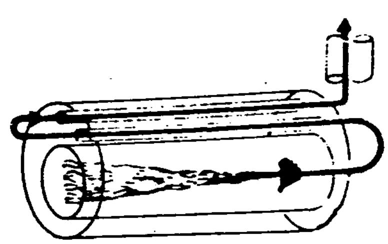


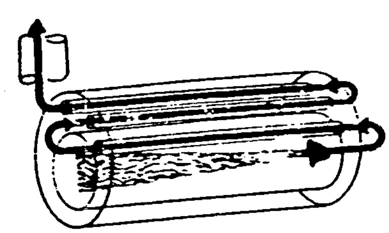
FIGURE 2-3. SCOTCH BOILER



2 PASS



3 PASS



4 PASS

FIGURE 2-4. TWO, THREE, AND FOUR PASS SCOTCH BOILER DESIGNS

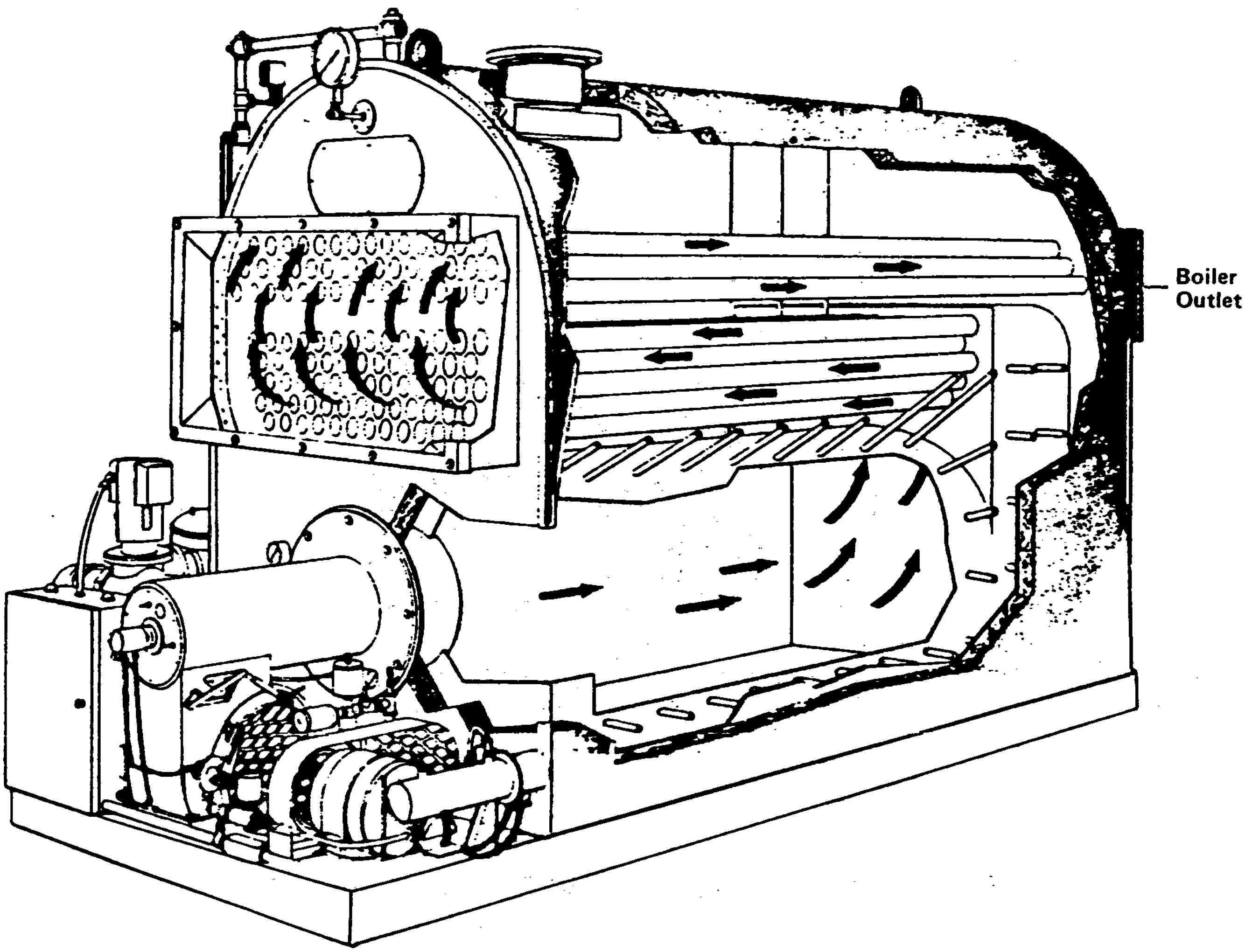


FIGURE 2-5. HORIZONTAL RETURN TUBULAR BOILER

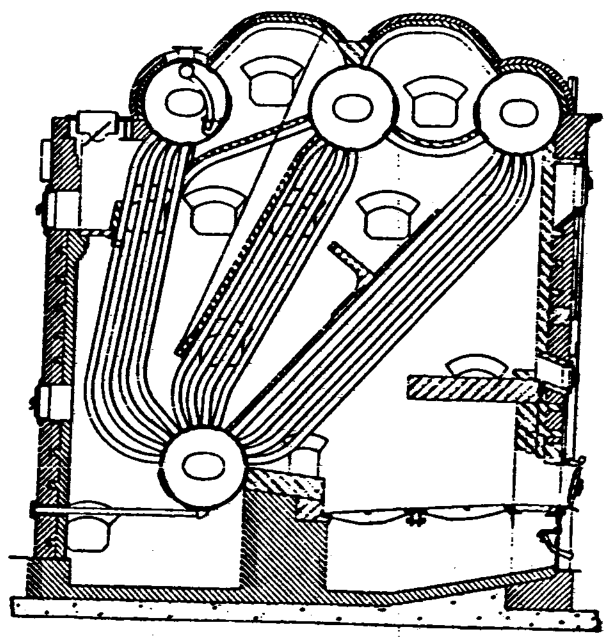


FIGURE 2-6. FOUR DRUM WATER TUBE BOILER

tubes for good heat transfer. Two drum boilers have generally replaced three and four drum units in modern construction, because they are less expensive to construct.

a. Refractory Furnaces. Early boiler designs utilized refractory furnaces as combustion zones. Some furnaces used arches and bridge walls to reflect heat and maintain high temperatures in specific zones for burning anthracite and other hard coals. Since prolonged exposure to high temperature damages refractory material, it is necessary to maintain the heat limberation rate (Btu per hour per cubic foot of furnace volume) of refractory furnaces within reasonable limits. These limits depend upon the type of refractory used, type of fuel, firing method, type of heating surface exposed to the radiant heat, and type of cooling mechanism used. Maximum heat liberation rates for refractory furnaces are in the ranges of 25,000 to 35,000 Btu per hour per cubic foot at full load. In refractory wall constrution it is important to allow for the thermal expansion which occurs as the refractory is heated to operating temperatures. Figure 2-7 illustrates typical expansion joint arrangements. The development of high alumina super-duty firebrick, insulating firebrick, blok insulation, castable refractory, and plastic refractory have greatly improved refractory life and reduced radiation losses from boiler furnaces. The NAVFAC "Central Heating Plant" Manual MO-205 discusses refractories in greater detail.

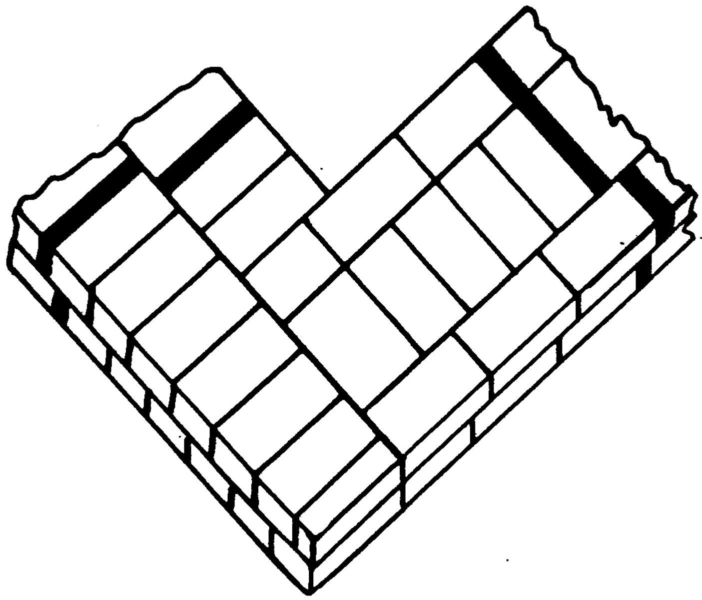
b. Water Wall Construction. Water walls were developed to allow the use of higher firing rates and higher furnace heat release rates, while reducing heat losses and maintenance. Improvements to water wall furnaces and associated casings and lagging also reduce air infiltration into the boiler, reducing excess air levels and improving boiler efficiency. The four types of water wall construction are: tube and tile, tangent tube, studded tube, and membrane wall (reference figure 2-8). The tube and tile construction which was first developed provided only a partial solution to the maintenance and heat loss problems. Minimum practical tube spacing is limited by ability to economically roll the tubes into drums or headers. This, in turn, limits the amount of heat transfer surface added and the amount of protection given to the refractory, and thus limits the practicality of tangent tube construction. Studded tube construction was then developed and was highly effective. In areas with high heat releases such as bridge walls and arches, studded tubes covered with refractory are especially effective. Flue gas can still leak through studded tube wall construction under some circumstances, resulting in corrosion of boiler tubes, and lagging. To obtain completely gas-tight construction and maximize heat transfer, membrane water wall construction was developed and remains the best, though most expensive, water wall design.

c. Steam Drum Internals. Steam drums are equipped with mechanical separators to ensure that the steam leaving the boiler does not contain solids or other impurities and that steam-free water is made available to continue the natural circulation process in the boiler. A dry pipe, the earliest device used, was placed inside the shell or drum just below the steam outlet nozzle. Numerous mall holes drilled in the upper half of the dry pipe cause separation of the steam from the water. The trend in boiler design toward ever higher heat transfer rates makes separation of water and steam more difficult and limits the application of the dry pipe. Combinations of baffles, cyclone-type separators, corrugated scrubbers, and perforated plates are now used to effectively separate water and steam. Figure 2-9 illustrates modern steam drum internals. The cyclones are arranged in a row and receive the water/stean mixture tangentially from the boiler water wall and generating tubes. The water is spun to the outside of the yclone and exits through the open bottom of the cyclone. The steam is less dense and thus stays in the center and exits through the open top of the cyclone. Scrubbers further reduce the amount of water entrained. Solids in ondensed steam from a well-designed steam drum should be less than 3 ppm.

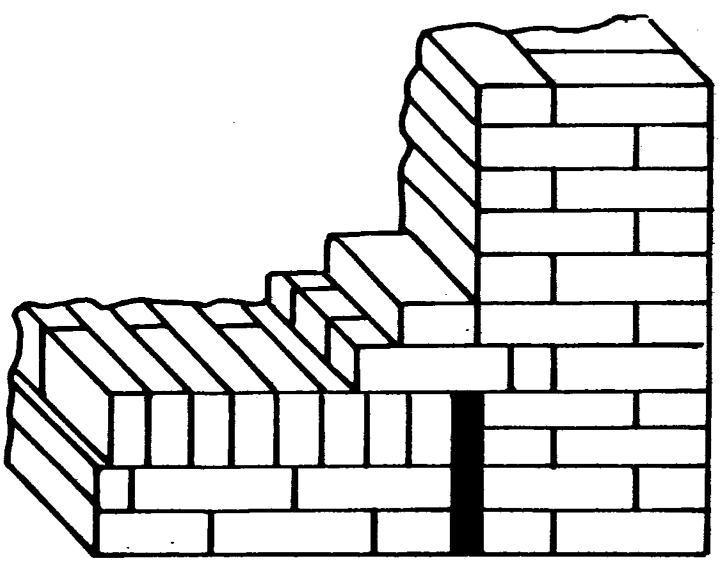
d. Generating Surface. Boiler tubes that connect the upper and lower drums are called generating surfaces and are included with the water wall surface in computing the total heating surface. Many different tube spacings are used, depending on the type of fuel being fired. The tubes may be inline or staggered. A staggerred tube arrangement would not be acceptable for coal- or heavy oil- fired boilers due to its susceptibility to ash buildup; however, it provides better heat transfer for gas- or light oil-fired units.

e. Superheaters. Some processes and turbines require steam that is super-heated above the saturated steam temperatures. Figure 2-10 illustrates a two-drum boiler equipped with a superheater, water walls, spreader stoker, and economizer. The steam from the steam drum is directed to a superheater inlet header and then through the superheater tubes to the outlet header and steam outlet. A superheater can be arranged in many ways and may be located behind a row of generating tubes. These tubes cool the furnace gases somewhat before reaching the superheater tubes and shield the superheater tubes from radiant heat. Superheaters are not commonly found in Army Central Boiler Plants.

f. Package Boilers. Packaged water tube boilers are factory-assembled, complete with combusion equipment, mechanical draft equipment, automatic controls , and accessories. These factory-assembleld packages can be purchased in capacities exceeding 200,000 lb/hr. Package boilers are available in three basic configurations: "D", "A", and "O" (Figure 2-11). Figure 2-12 illustrates a "D" type package boiler arranged for oil and gas firing. Note

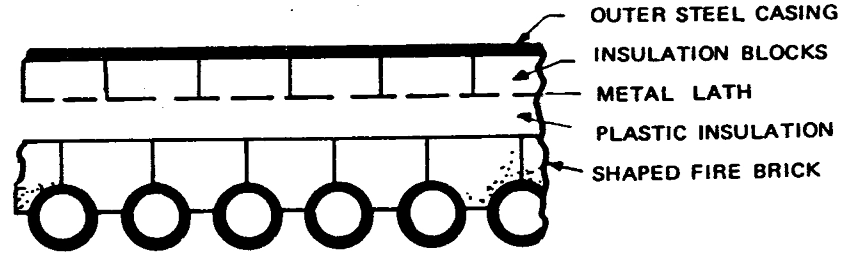


Corner Construction With
Staggered Expansion Joints
(18" Wall)

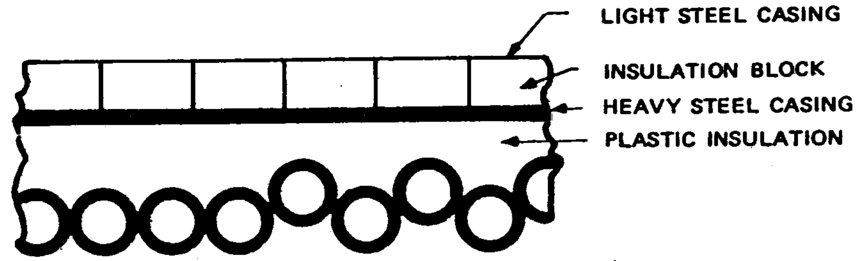


Floor to Wall Expansion Joint

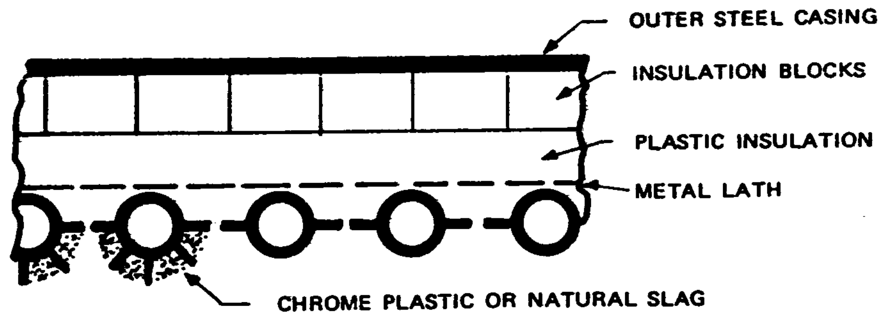
FIGURE 2-7. REFRACTORY EXPANSION JOINTS



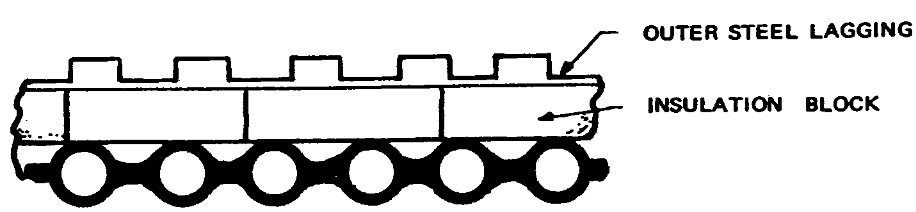
TUBE AND TILE



TANGENT TUBE



STUDDED TUBE



MEMBRANE WALL

FIGURE 2–8. WATER WALL CONSTRUCTION

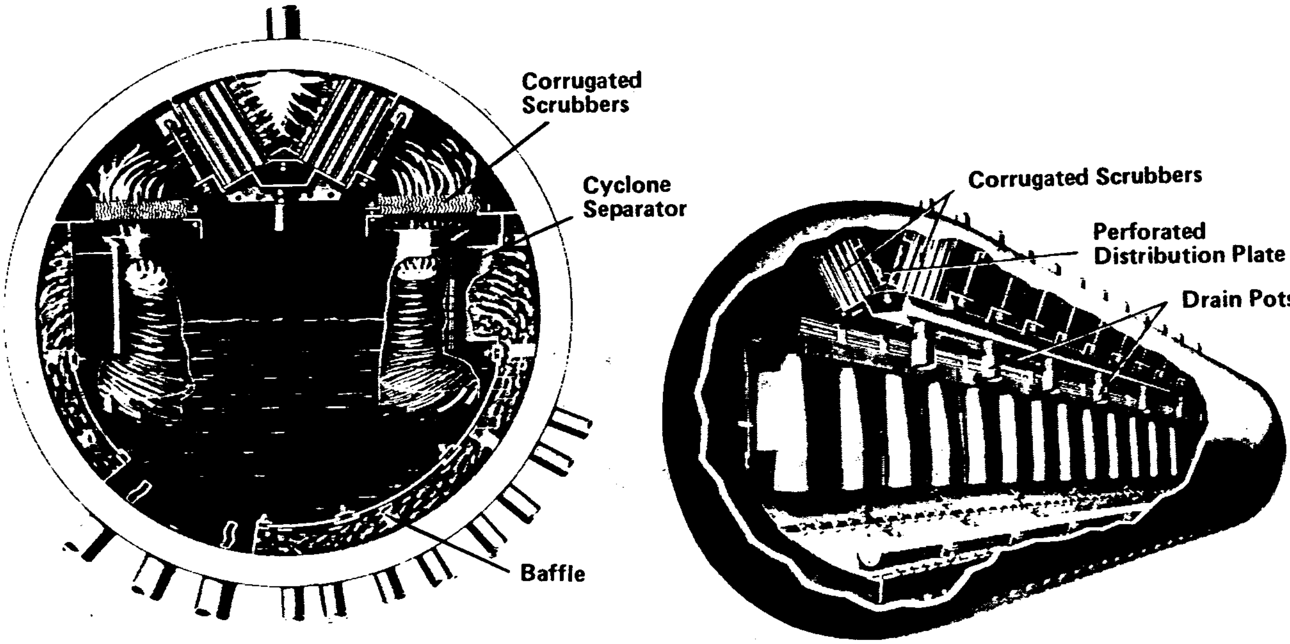


FIGURE 2-9. STEAM DRUM INTERNALS

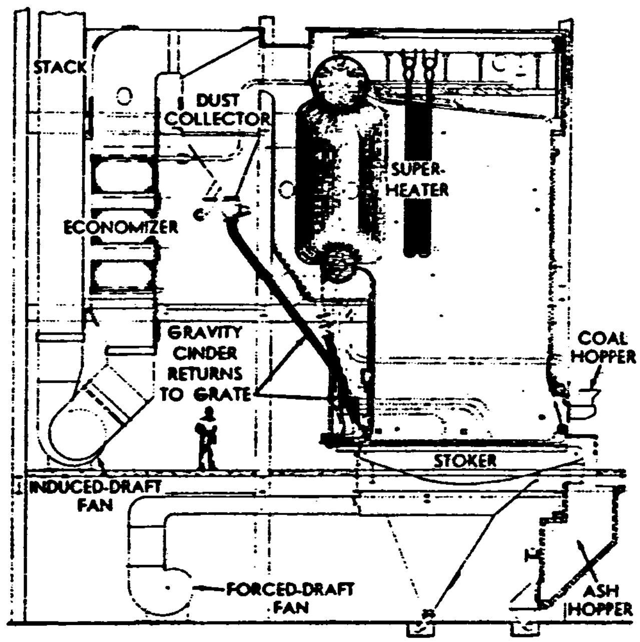


FIGURE 2-10. SUPERHEATER IN TWO DRUM BOILER

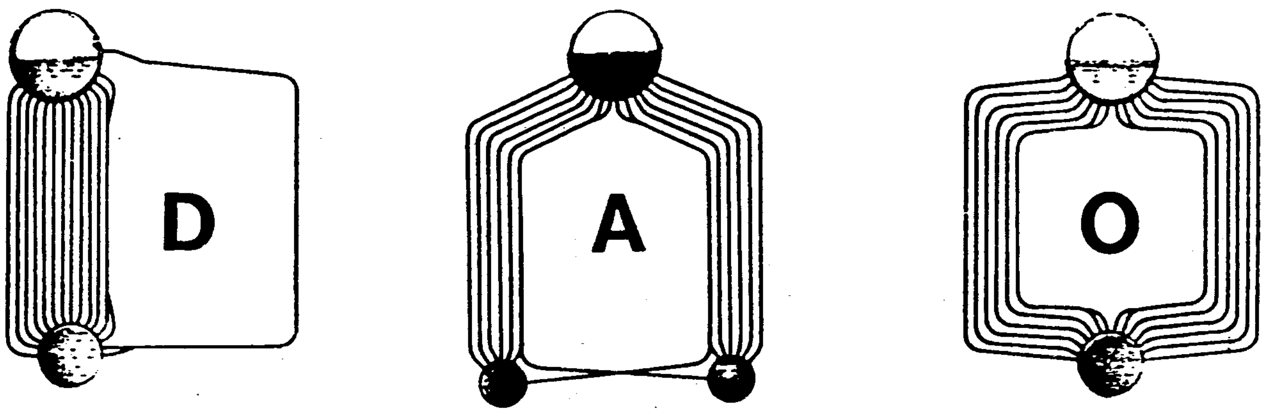


FIGURE 2-11. PACKAGE BOILER CONFIGURATIONS

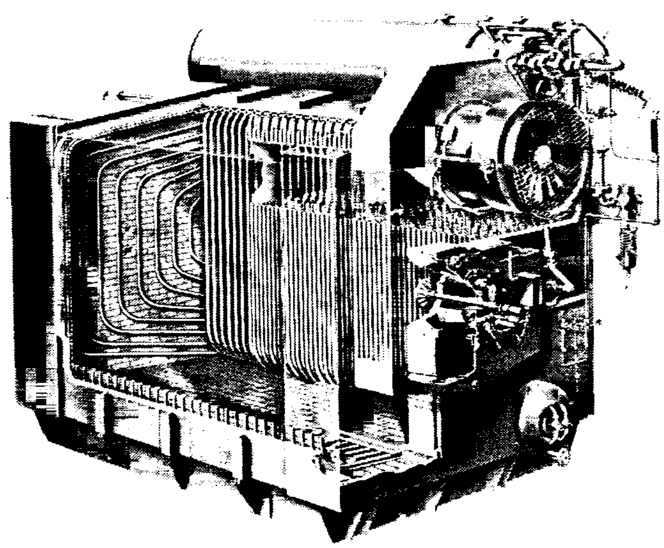


FIGURE 2-12. "D" PACKAGE BOILER

that the flame travels lengthwise down the furnace where combustion is completed. The flue gases then make a 180° turn and come back to the burner end of the boiler, exiting from the side of the generating bank tubes. Historically, package boilers have been designed to fire only natural gas and oil. Coal firing has not been practical due to the high ash content of the coal which would plug the boiler generating banks. Package boilers have been widely and successfully applied for Central Boiler Plant service.

2.6. HOT WATER GENERATORS.

Hot water generators are often called hot water boilers, even though little or no boiling occurs. Modified Scoth boilers and a variety of package boilers are available. These boilers have limited and uneven water circulation characteristics if natural circulation is utilized because of the small natural circulation forces available. Special boilers have thus been developed that use forced circulation to improve heat transfer rates. Figure 2-13 illustrates this type of hot water generator. Note that the steam and mud drums have been replaced with headers. The hot water generator is connected to a hot water distribution system. As water is heated in the hot water generator, the water expands. When the hot water is distributed to various heat exchangers, as illustrated in figure 2-14. the water cools and contracts. An expansion drum, pressurized by either steam or inert gas, is provided to adjust for these volume changes. One or more centrifugal pumps are required to cirulate water through the system. Figure 2-15 illustrates a high temperature water system equipped with a steam-pressurized expansion drum, a circulating pump for the generator, and a circulating pump for the distribution system. Many other arangements are possible. A more detailed discussion of hot water generators and distribution systems is provided in Army Manual TM 5-810-2, entitled "High Temperature Water Heating Systems."

2-7. ECONOMIZERS.

Economizers are used to recover heat from the boiler flue gases and thereby increase boiler efficiency. The heat absorbed by the economizer is transferred to the boiler feedwater flowing through the inside of the economizer tubes. Because feedwater temperatures are much lower than saturated steam temperature, an effective temperature differential exists, enabling good heat transfer and low economizer exit gas temperatures. Continuous tube construction is common. Bare tubes are used for coal-fired boilers, while fin-tubes or extended surfaces are commonly used on gas- and oil-fired units. Figure 2-16 shows a continuous bare tube economizer. Figure 2-17 illustrates a steel-finned extended surface economizer. The extended surface promotes heat transfer from the gas by providing more heating surface. Care must be taken when selecting the number of fins per inch. Extended surface economizers on natural gas-fired boilers may use up to nine fins per inch, while only two fins per inch would be used for heavy oil-fired applications. Provision for cleaning with sootblowers is necessary for economizers on coal- or oil-fired boilers. Economizers are usually arranged with gas flow down and water flow up. This maximizes heat transfer and helps to avoid water hammer. Economizers are usually designed with water temperatures below the saturated temperature of the water to avoid producing steam. Economizers should be equipped with three-valve bypass on the water side to allow servicing or bypassing water at low boiler loads. This helps to minimize economizer corrosion when high sulfur fuels are burned. Figure 2-18 provides curves which establish minimum metal temperatures allowable for corrosion protection in economizers and air heaters. Since the water temperature in the economizer is normally above 212° F, the fuel sulfur content would have to be less than 2% for stoker-fired coal or 2.6% for oil-fired boilers to minimize corrosion problems during operation. Methods for avoiding corrosion during idle or standby periods are discussed in paragraph 3-27. Economizers are pressure parts and, as such, must be manufactured and stamped in accordance with the ASME Boiler and Pressure Vessel Code. Economizers equipped with three-valve bypasses must be equipped with one or more safety valves.

2-8. AIR HEATERS.

Air heaters, like economizers, are used to recover heat from boiler flue gases and thereby increase the boiler efficiency. The heat absorbed by the air heater is transferred to the combustion air befor the air enters the burners and boiler. This preheated air not only improves efficiency by recovering otherwise lost heat, but also can improve the combustion of some fuels by promoting higher furnace temperatures. There are two general types of air heaters. Recuperative air heaters, like the tubular air heater illustrated in figure 2-19, transfer heat from the hot flue gases on one side of the tube to the combustion air on the other side of the tube. Regenerative air heaters, like the rotary heat wheel illustrated in figure 2-20, transfer heat indirectly by heating a plate with the hot gas and then rotating that hot plate into the cool combustion air which then absorbs the heat. Rotary heat wheels are equipped with seals that separate the flue gas side from the combustion air side of the wheel. Air infiltration from the air side to the gas side is minimized but not eliminated, and is a factor which must be considered when sizing forced and induced draft fans. Provisions for sootblowers are required if dirty or high-ash fuels are being fired. Cold

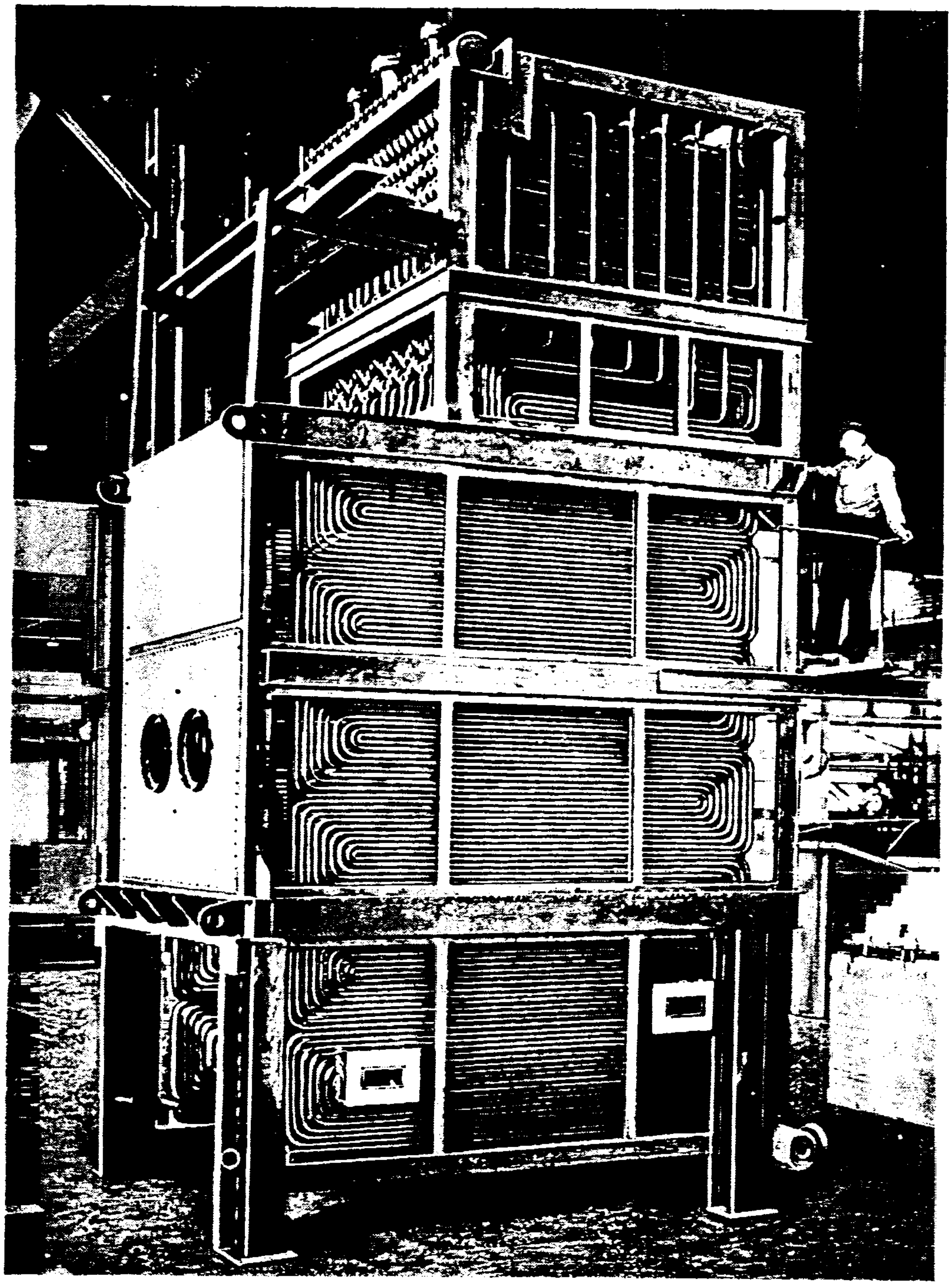


FIGURE 2-13. HOT WATER GENERATOR

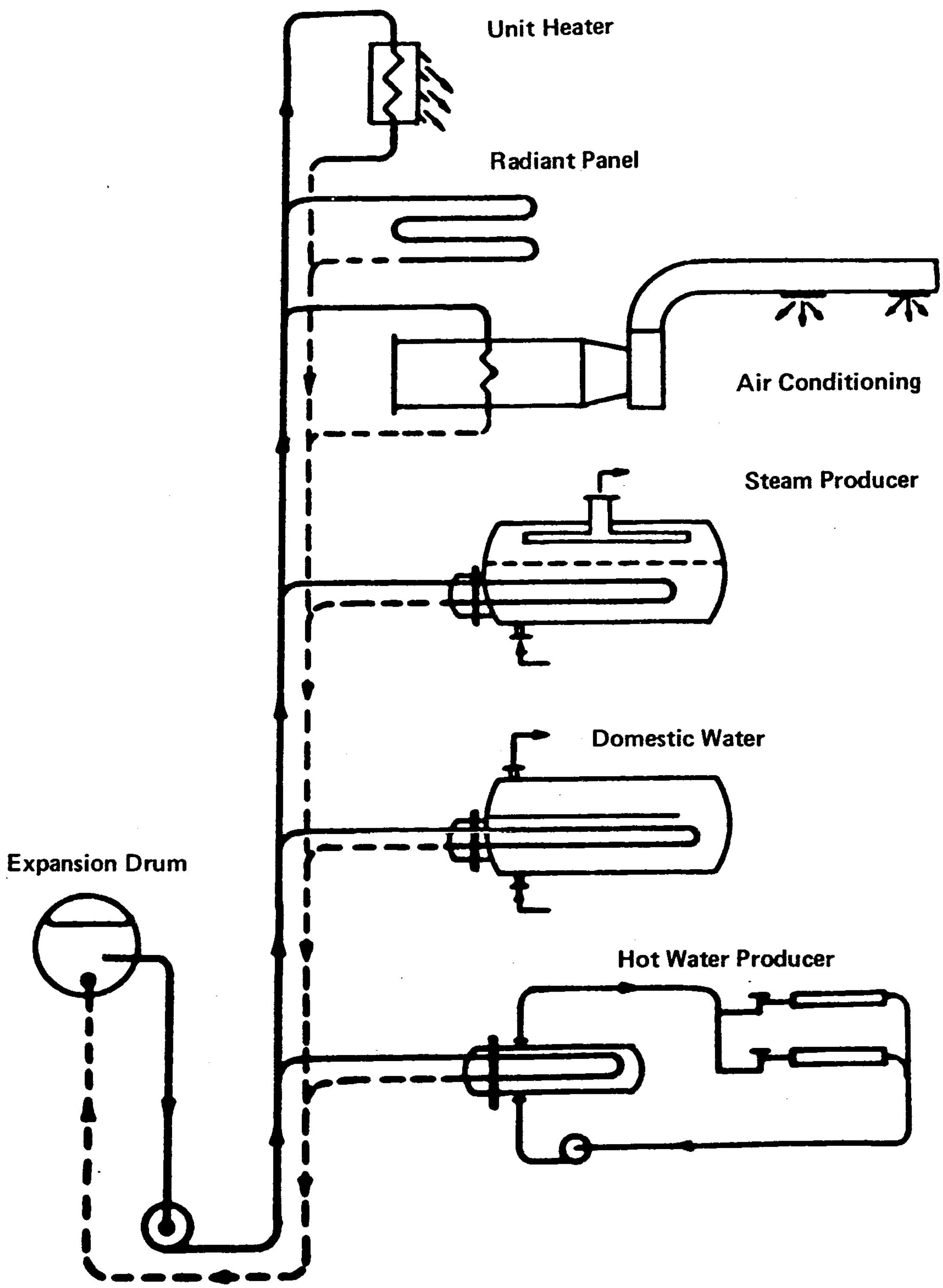


FIGURE 2-14. HOT WATER END USES

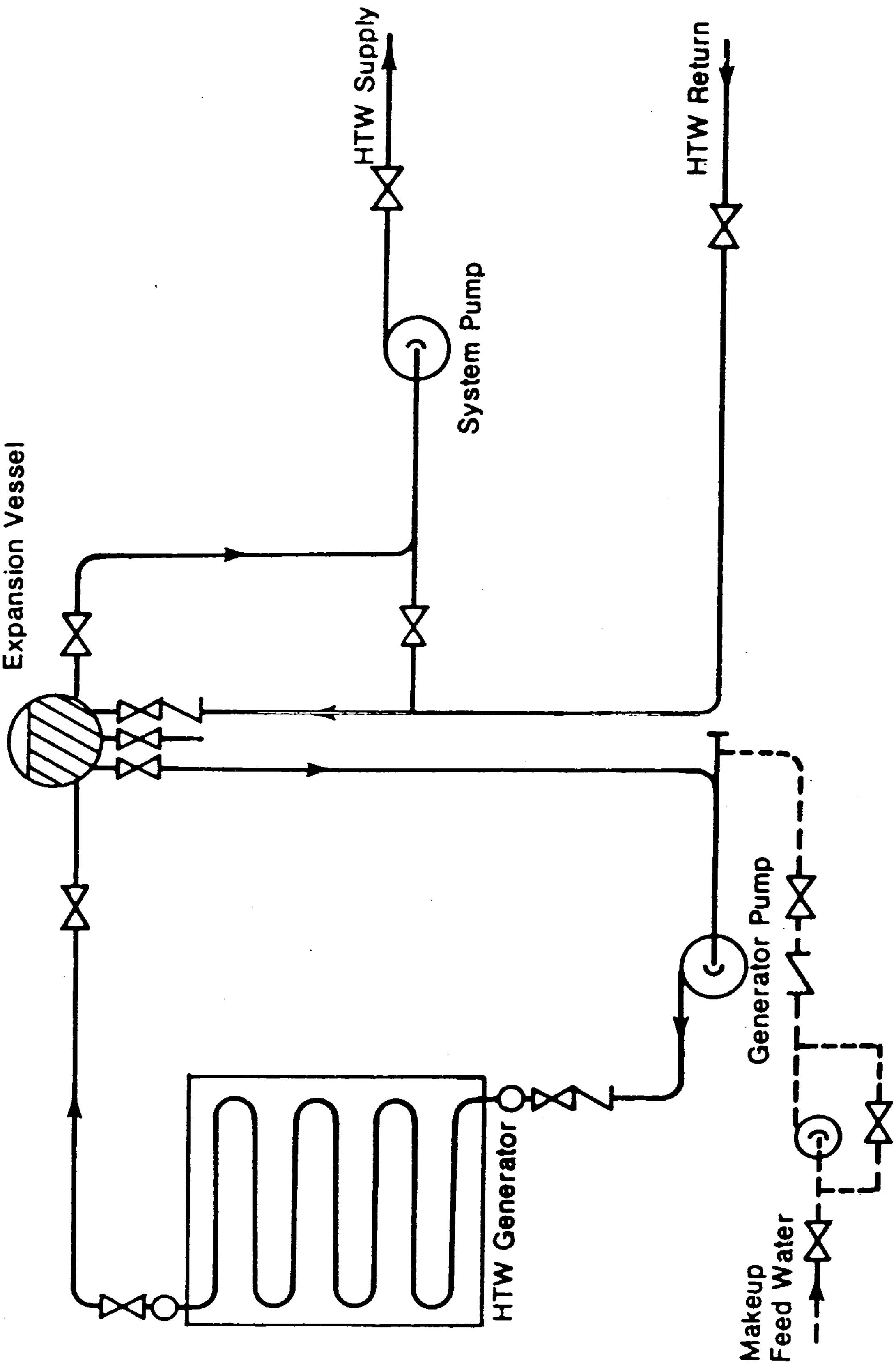


FIGURE 2-15. HOT WATER DISTRIBUTION

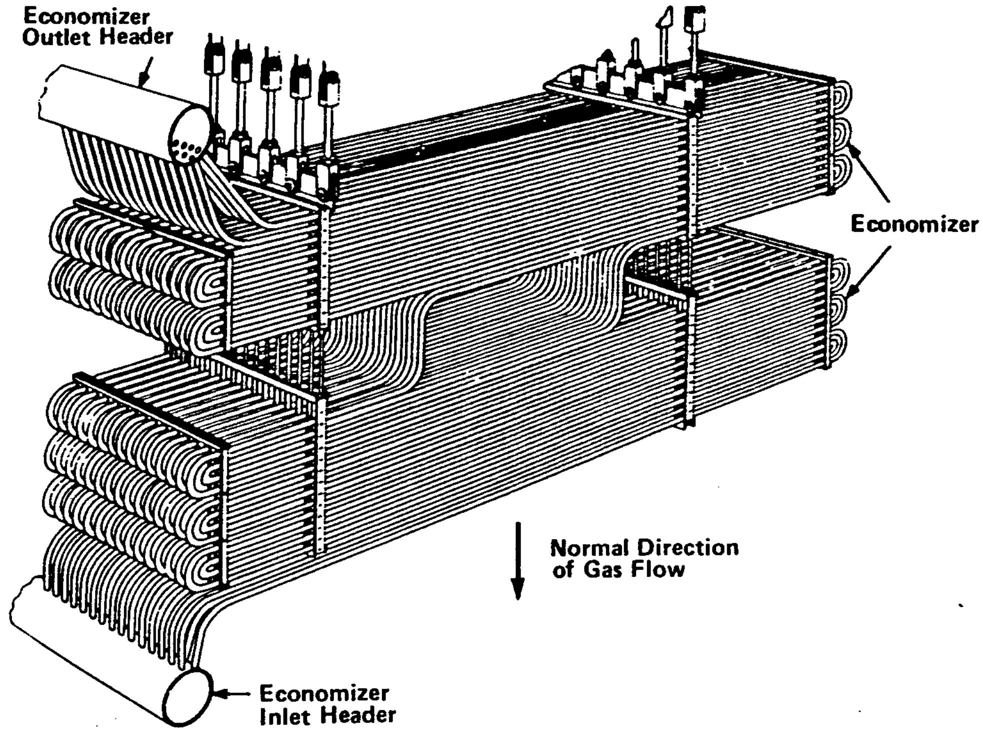


FIGURE 2-16. BARE TUBE ECONOMIZER

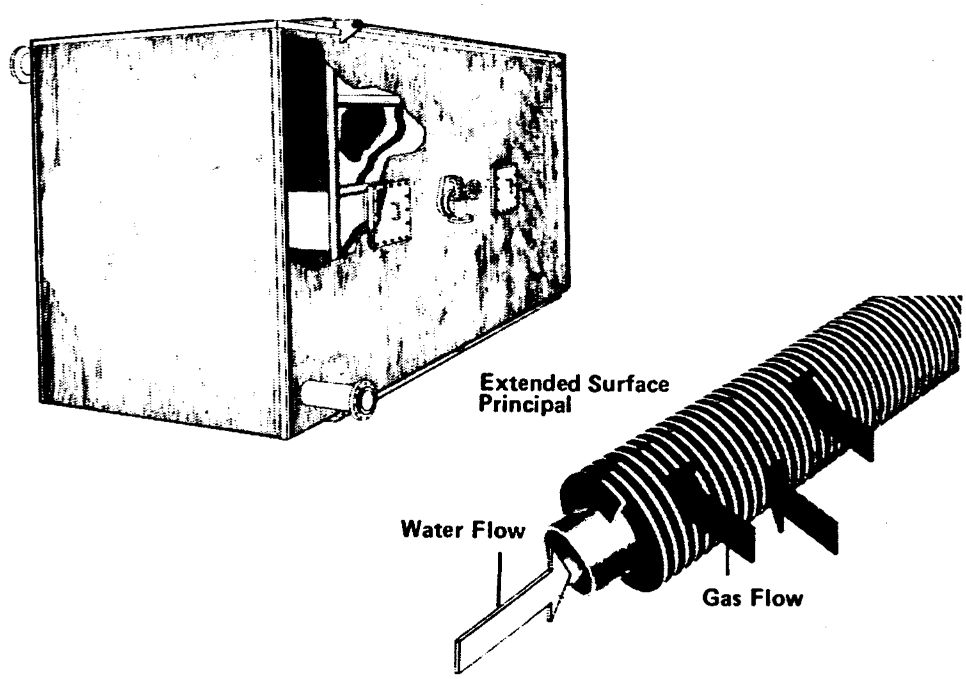


FIGURE 2-17. EXTENDED SURFACE ECONOMIZER

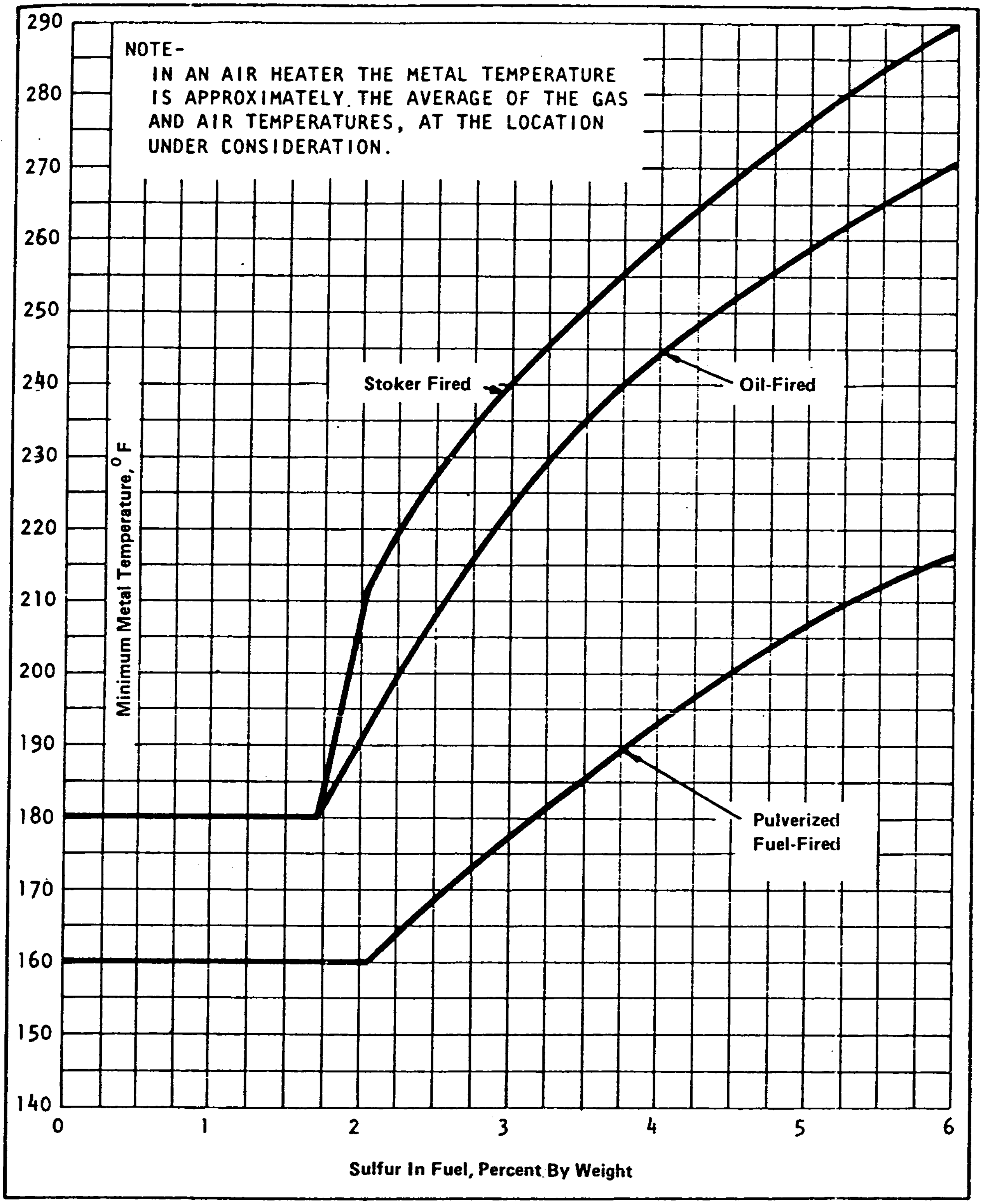


FIGURE 2-18. COLD END CORROSION - MINIMUM METAL TEMPERATURES

end corrosion is more of a problem in an air heater than an economizer because of the low entering combustion air temperatures. Figure 2-18 establishes minimum allowable metal temperature if corrosion is to be controlled. Cold air bypass ducts and dampers, hot air recirculation, steam coil air heaters, and low- level economizers are examples of methods for preheating the combustion air before it enters the air heater. These methods help control cold end corrosion but also reduce the efficiency of the system by raising exit gas temperatures.

SECTION II. BOILER ACCESSORIES AND FITTINGS

2-9. ASME REQUIREMENTS.

To ensure safe operation, the ASME Boiler and Pressure Vessel Code requires that boilers be equipped with a water gage glass and gage cocks, water column, pressure gage, and safety valves. Forced circulation, high temperature water boilers which have no water line do not require a gage glass and gage cocks, but a temperature gage is required. Detailed requirements for the location and installation of these accessories on power boilers are found in Section I of the ASME Boiler and Pressure Vessel Code, and the requirements for heating boilers are in Section IV. Section IV requires each boiler to be equipped with two controls to cut off the fuel supply so as to prevent steam pressure or water temperature from exceeding boiler limits. These controls are pressure operated for steam boilers and temperature operated for hot-water boilerts. Low-water fuel cutoff instrumentation is also required. Oil and gas-fired boilers must be equipped with suitable flame safeguard controls, safety limit controls, and burners which are approved by a nationally recognized organization.

2-10. GAGE GLASS, GAGE COCKS.

Each boiler must have at least one water gage glass. If the operating pressure is 400 psig or greater, two gage glasses are required on the same horizontal line. Eaqch gage glass must have a valved drainj, and the gage glass and pipe connections must not be less than ½ inch pipe size. The lowest visible part of the gage glass must be at least 2 inches above the lowest permissible water level, which is defined as the lowest level at which there is no danger of overheating any part of the boiler during operation. For horizontal fire tube boilers the age glass is set to allow at least 3 inches of water over the highest point of the tubes, flues, or crown sheet at its lowest reading. Figure 2-21 illustrates a typical water gage. Each gage consists of a strong glass tube connected to the boiler or water column by two special fittings. Thee fittings sometimes have an automatic shutoff device that functions if the water glass falls. Requirements for the fabrication of these shutoff devices are also given in the ASME Code. When the boiler operating pressure exceeds 100 psig, the gage glass must be furnished with a connection to install a valved drain to some safe discharge point. Each boiler must have three or more gage or try cocks located within the visible length of the gage glass. Gage cocks are used to check the accuracy of the boiler water level as indicated by the gage glass. They are opened by handwheel, chain wheel, or lever, and are closed by hand, a weight, or a spring. The middle cock is usually at the normal water level of the boiler; the other two are spaced equally above and below it. Spacing depends on the size of the boiler.

2-11. WATER COLUMNS

A water column is a hollow cast-iron, malleable-iron, or steel vessel lhaving two connections to the boiler. The top connection enters the steam space of the boiler through the top of the shell or head, and the water connection enters the shell or head at least 6 inches below the lowest permissible water level. The pipe used to connect the water column to the boiler may be brass, iron, or steel, depending on the pressure; it must be at least 1 inch in diameter. Valves or cocks are used in these connecting lines if their construction prevents stoppage by sediment deposits and if the position of the operating mechanism indicates whether they are open or closed. Outside screw-and-yoke-type gate valves are generally used for this service. Lever-lifting-type gaate valve or stop cocks with permanently attached levers arranged to indicate open or closed position may also be used. **These valves or cocks must be locked open.** Crosses are generally used in place of elbows or tees on the piping between the water column and the boiler to facilitate cleaning the line. A valved drain or blowdown line is connected to the water column for removal of mud and sediment from the lines and column. Ends of all blowdowns should be open and located for ease of inspection. The water column shown in figure 2-22 is equipped with high- and low-water alarms which operate a whistle to warn the operator. The whistle is operated by either of the two floats.

2-12. PRESSURE GAGE, TEMPERATURE GAGE.